A Problem in Cyclone Engineering

"I really don't know if it's worth the trouble," said John, "to redesign the seal for this one order. I don't anticipate any more requests for units using a fluid temperature this high."

John Hughs, Vice-President in Charge of Engineering with Cyclone Manufacturers, Inc. in Atlanta, Georgia, was discussing a recent order with Bill Wisner, a project engineer. The order had come in from Redstone Paints Company through one of Cyclone's sales engineers. Redstone was pumping gilsonite, an asphaltic material which is used in manufacturing paints and lacquers, over a long distance to be refined at one of their plants. The cyclones they ordered were to be used to separate solid contaminants from the gilsonite during the refining process.

Prepared in the Design Division, Department of Mechanical Engineering, by Robert Martin under the direction of Professor H. O. Fuchs with financial support form the National Science Foundation.

Exhibit 1 is a sketch of the cyclone ordered by Redstone which identifies the parts of the assembly (drawings of the individual parts are shown in succeeding exhibits). The gilsonite would be pumped into the unit through the pipe on the top right-hand side. The space between the cyclone body (Exhibit 2) and the outer housing (Exhibit 3) would fill with gilsonite. The fluid would then be forced into the cyclone body through the feed entrance in the cyclone head (Exhibit 4). The gilsonite when entering the unit would be at a temperature of 500° F and 250 psi pressure.

The seal presently used at the bottom of the unit requires two steel washers (Exhibit 5), one rubber washer (Exhibit 6), and a steel bushing (Exhibit 7). The unit is sealed at the bottom by sliding a steel washer followed by a rubber washer and a second steel washer onto the cyclone body. The steel bushing is then screwed into the outer housing, causing the rubber washer to be squeezed between the two steel washers to effect the seal.

John continued in his discussion with Bill. "If we could design a new seal it would add some flexibility to the use of our cyclones. But whatever changes we make must be economical and the new seal must be interchangeable with the seal we are presently using."

"It appears to be a matter of finding the right material to use as a flexible washer," said Bill. "The rubber washers we are using won't last long at temperatures of 500° F under 250 psi pressure. And the fact that rubber and gilsonite react chemically doesn't help at all."

"Yes, the right material would certainly solve our problems," said John, "but finding a suitable one will be difficult. We made some seal samples of silicone, which is supposed to be stable when subjected to high temperature and chemicals, but apparently this won't work

either. The samples we sent to Redstone for testing became brittle after being subjected to gilsonite at 500° F."

"Have the samples been returned to us for examination?" Bill asked. "No, we haven't received the samples yet, although I expect that it's the high temperature that's still causing the trouble. We are having some more samples made of Viton, but I don't know if this is going to do the job.

"Bill, since I'm not sure that we can find the right material I want you to change the seal design so that we can operate at high temperatures. The new seal will also have to be interchangeable with our present one."

A cyclone (Exhibit 8) is a device used for many types of separation such as separating solids from liquid, solids from solids, liquid from liquid, dust and liquid from gas, etc. The incoming fluid pressure is used to generate a rotational fluid motion which causes relative movement between the components of the mixture and permits the materials to be separated. In Exhibit 8, the mixture would be pumped into the cyclone through the feed entrance. The feed entrance gradually changes shape from a circular to a rectangular cross section. The mixture is injected tangentially into the cylindrical portion of the cyclone. The body of the cyclone can remain cylindrical for its entire length, but generally its lower portion is conical.

As the fluid rotates in the cyclone, the solids tend to move outward thus causing a high concentration of solids near the cyclone wall. This movement of solids is aided by shearing forces in the fluid in the outer regions of the cyclone. The main fluid outlet, the vortex finder, is located near or on the axis of the cyclone. The fluid which exits through the vortex finder is called the overflow and that which exits through the apex valve is called the underflow. When separating solids from a liquid,

the overflow will contain a small amount of solids and the underflow will be a small amount of fluid with a high concentration of solids.

Since the main fluid outlet is located at the top of the cyclone, the fluid flow pattern takes the form of a spiral within a spiral. Both of the spirals rotate in the same direction (Exhibit 9). When the fluid is injected tangentially into the cyclone, it begins a rotational downward movement creating the outer spiral. Because of the small apex opening and the location of the vortex finder some of the fluid must reverse direction and exit through the top of the cyclone thus creating the inner spiral. Within the inner spiral is an air core which extends the length of the cyclone.

At present, no theory has been able to completely describe the flow of fluid in a cyclone. The Navier-Stokes equations have been applied, but their solution requires several empirically evaluated constants to describe the conditions that exist. Many empirical formulas have been formed to describe the operation of a cyclone. To illustrate the variation in these empirical approaches, a number of formulas used to evaluate pressure drop are listed in Exhibit 10.

The vertical velocity of the fluid is downward near the wall and upward near the axis. The locus of zero vertical velocity is cylindrical with a diameter approximately 0.43 times the diameter of the cylindrical portion of the cyclone.

There exists an inward radial flow which has a maximum near the cyclone wall and diminishes as the radius decreases until it becomes zero at the air core interface.

In the outer region of the cyclone, the flow is similar to that of a vortex with the tangential velocity obeying the relation

$$VR^n = \text{constant} \qquad (1)$$

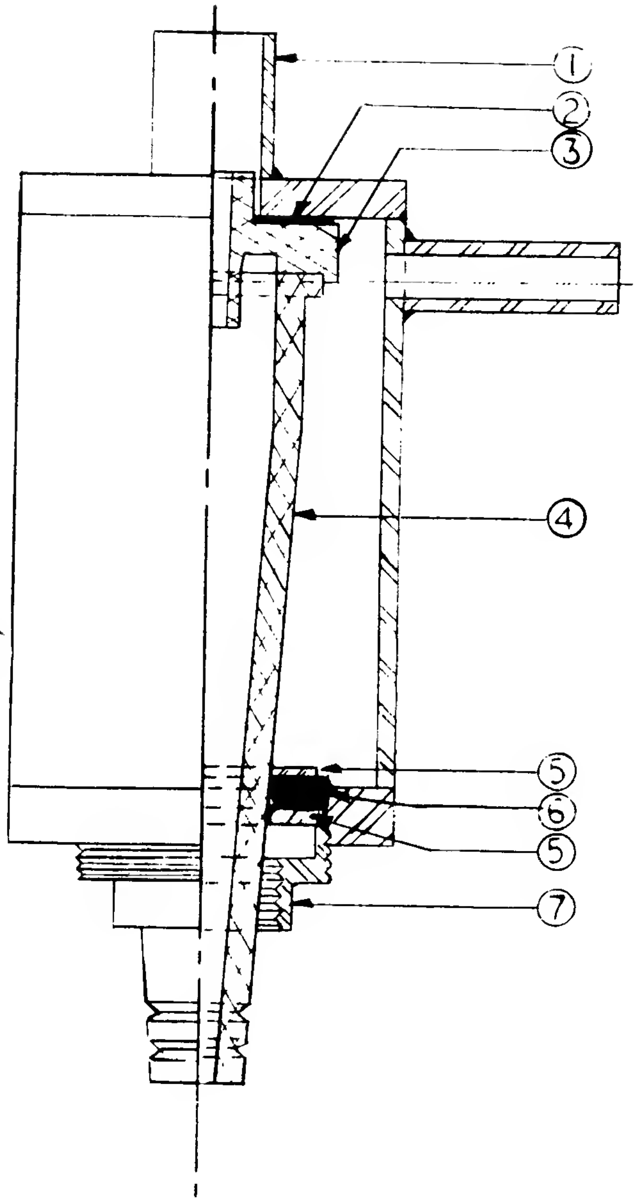
where V is the tangential velocity and R is the radius. Formula (1) is an empirical relation in which n takes on values from 0.5 to 1.0. However, at a sufficiently small radius the tangential velocity begins to decrease as the radius decreases. In this region the governing relationship is the one for solid body rotation,

$$\frac{V}{R} = \text{constant}$$

This relationship holds until the air core interface is reached.

List of Exhibits

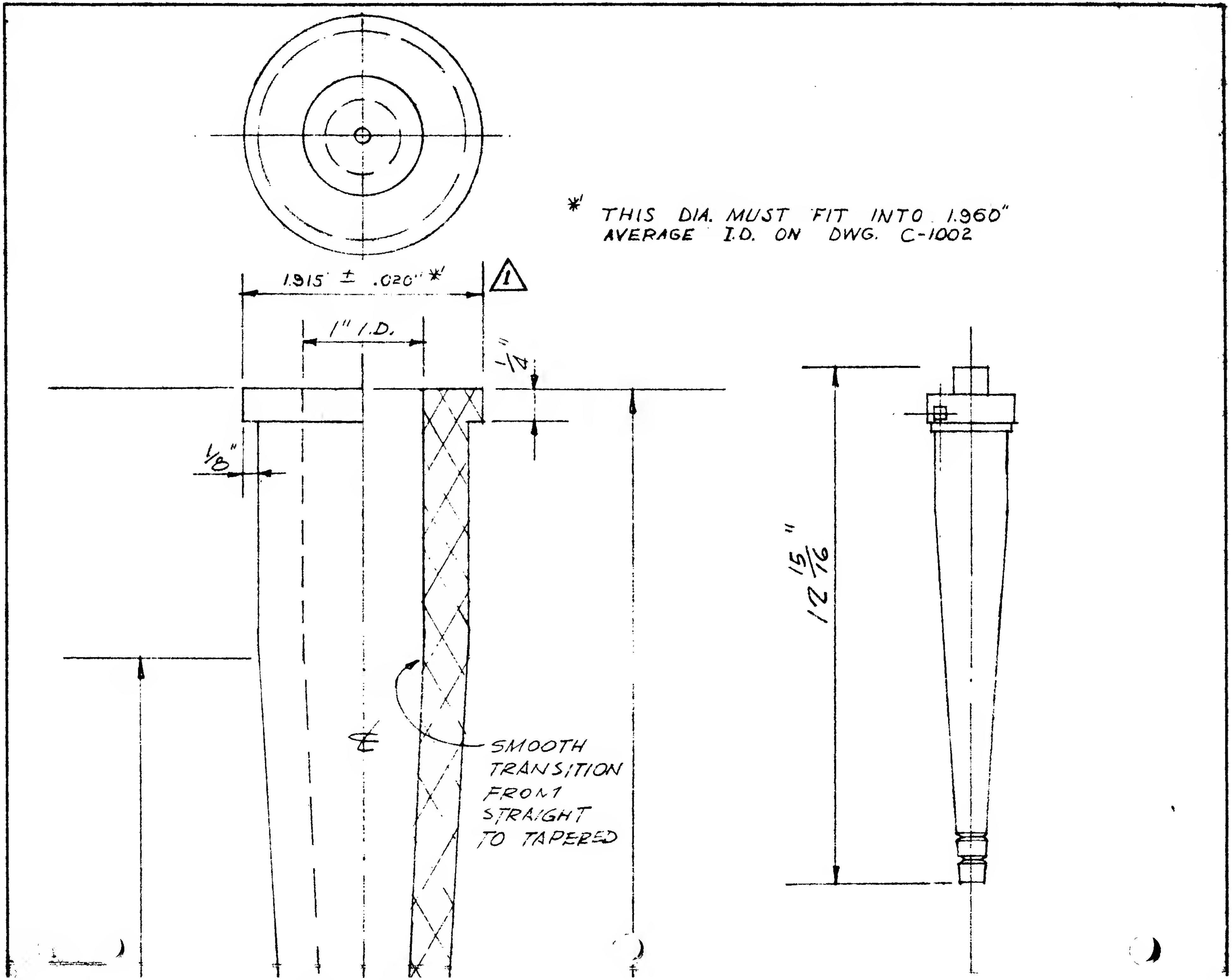
CYCLONE PARTS LIST



Item	Description
1	UniClone Housing, Mild Steel
	UniClone Housing, Stainless Steel
2	Rubber Gasket
3	Cyclone Head, Wearox
4	Cyclone Body, Wearox
5	Washer, Steel
	Washer, Stainless Steel
6	Rubber Washer
7	Bushing, Steel
	Bushing, Stainless Steel

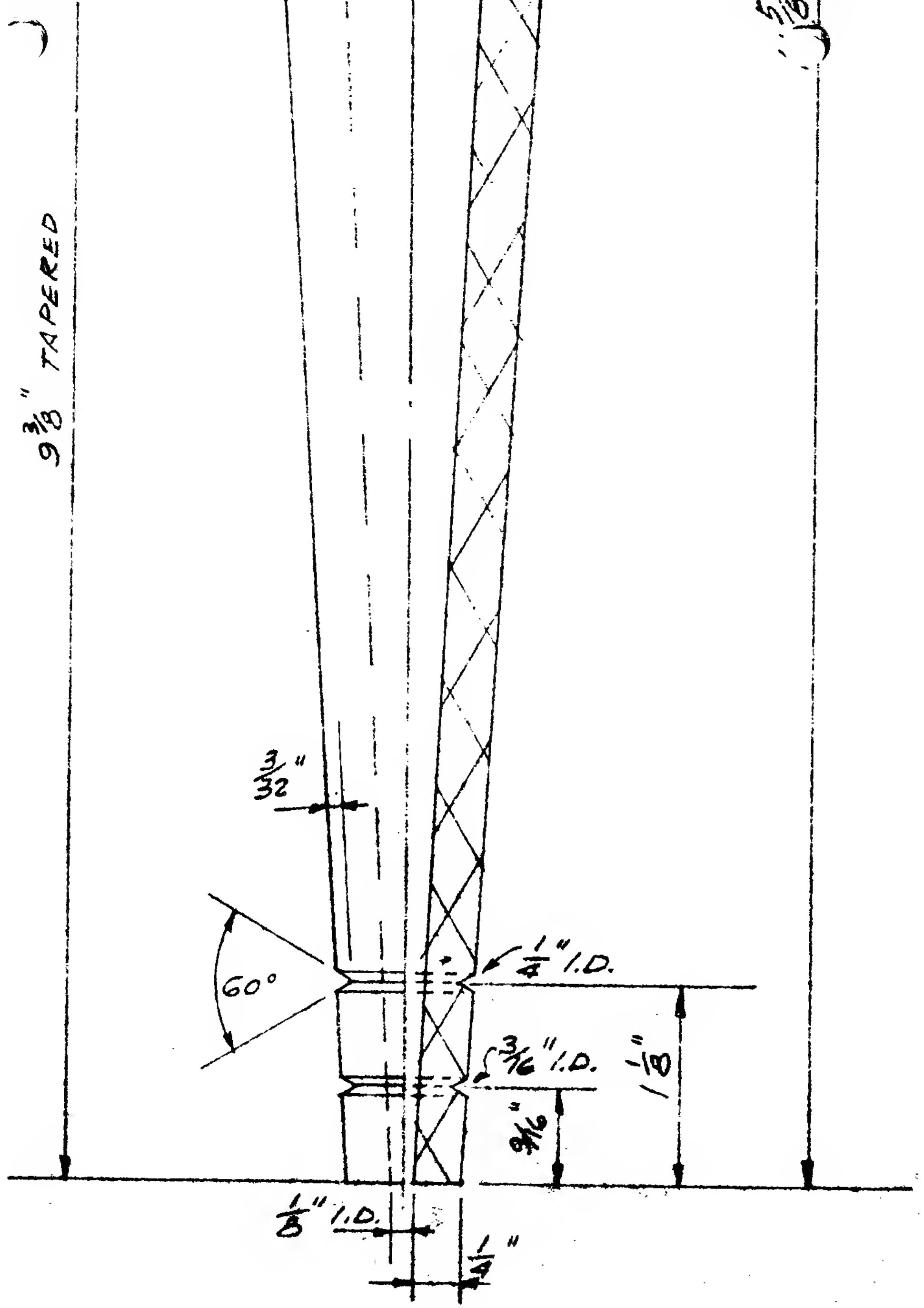
PLEASE SPECIFY PART NUMBER AND CYCLONE SERIAL NUMBER WHEN ORDERING PARTS

EXHIBIT 1 CYCLONE PARTS LIST



*' THIS DIA. MUST FIT INTO 1.960"
AVERAGE I.D. ON DWG. C-1002
1.915 ± .020" *'
1
1" I.D.
1/4"
1/8"
SMOOTH
TRANSITION
FROM
STRAIGHT
TO TAPERED
12 15/16"

ASSEMBLED CYCLONE



* M.O.C. INDICATES "MATERIAL OF CONSTRUCTION":

AO = WEAROX

SS = STAINLESS STEEL

U = URETHANE

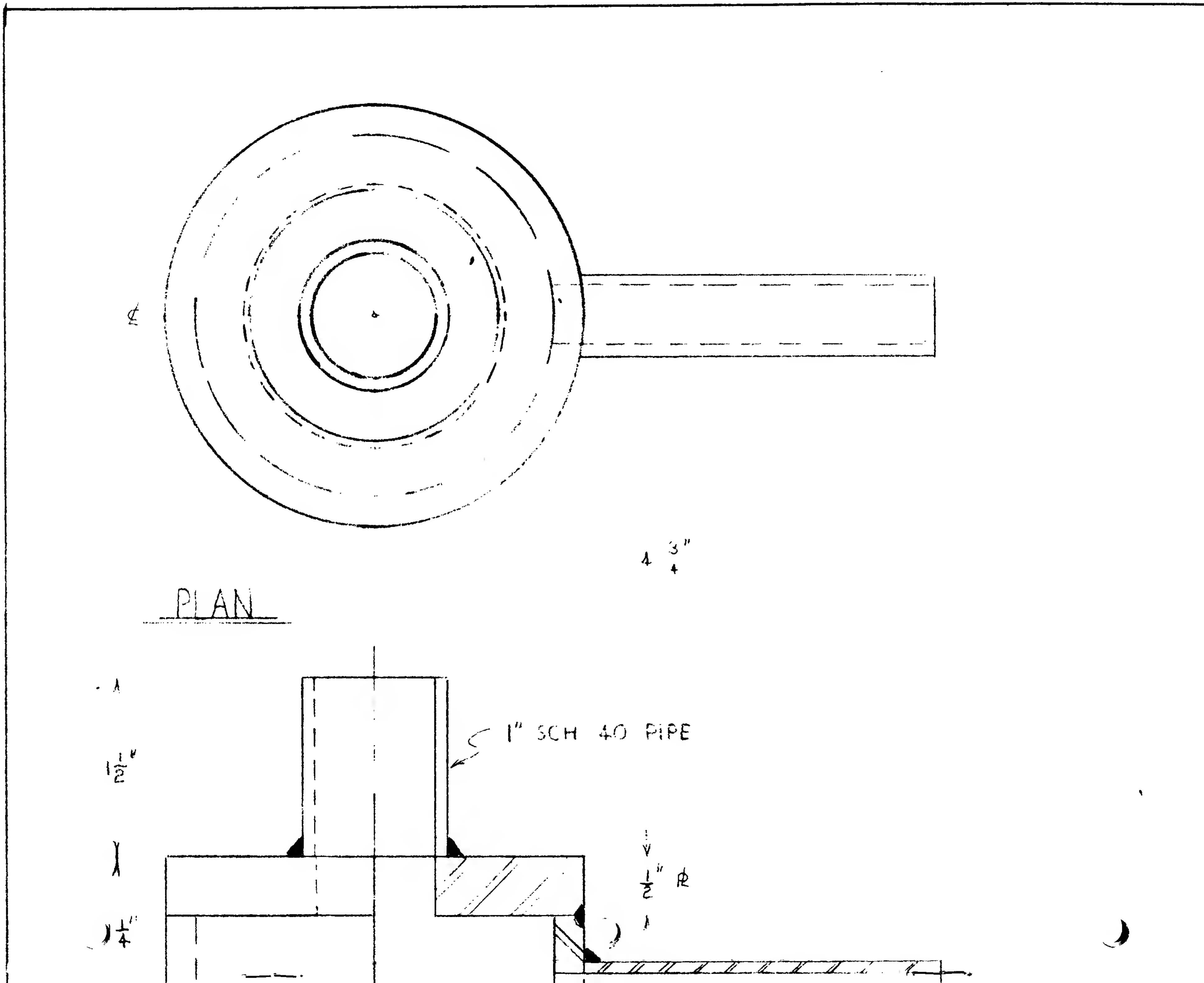
NY = NYLON

Scale: FULL	Date: 4-12-65	Drn. By: JR	Appd. By:

CYCLONE BODY
PART No. C1003-M.O.C.

Revisions: REVISED DIM. ... REVISED DIM. ... Dwg. No. C-1003

EXHIBIT 2 CYCLONE BODY



℄
PLAN
$4\frac{3}{4}$"
1" SCH 40 PIPE
$1\frac{1}{2}$"
$\frac{1}{2}$" ℞
$\frac{1}{4}$"

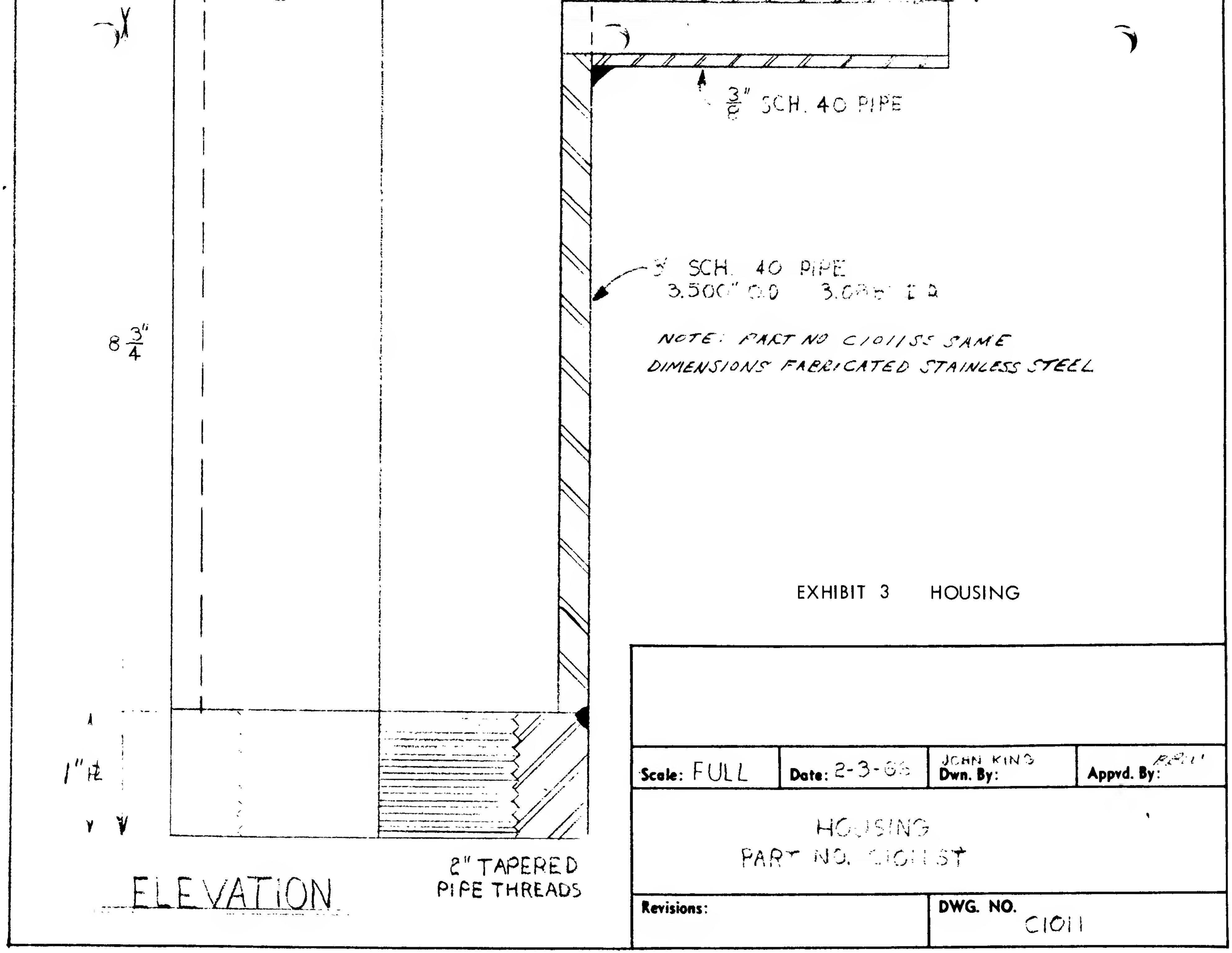


EXHIBIT 3 HOUSING

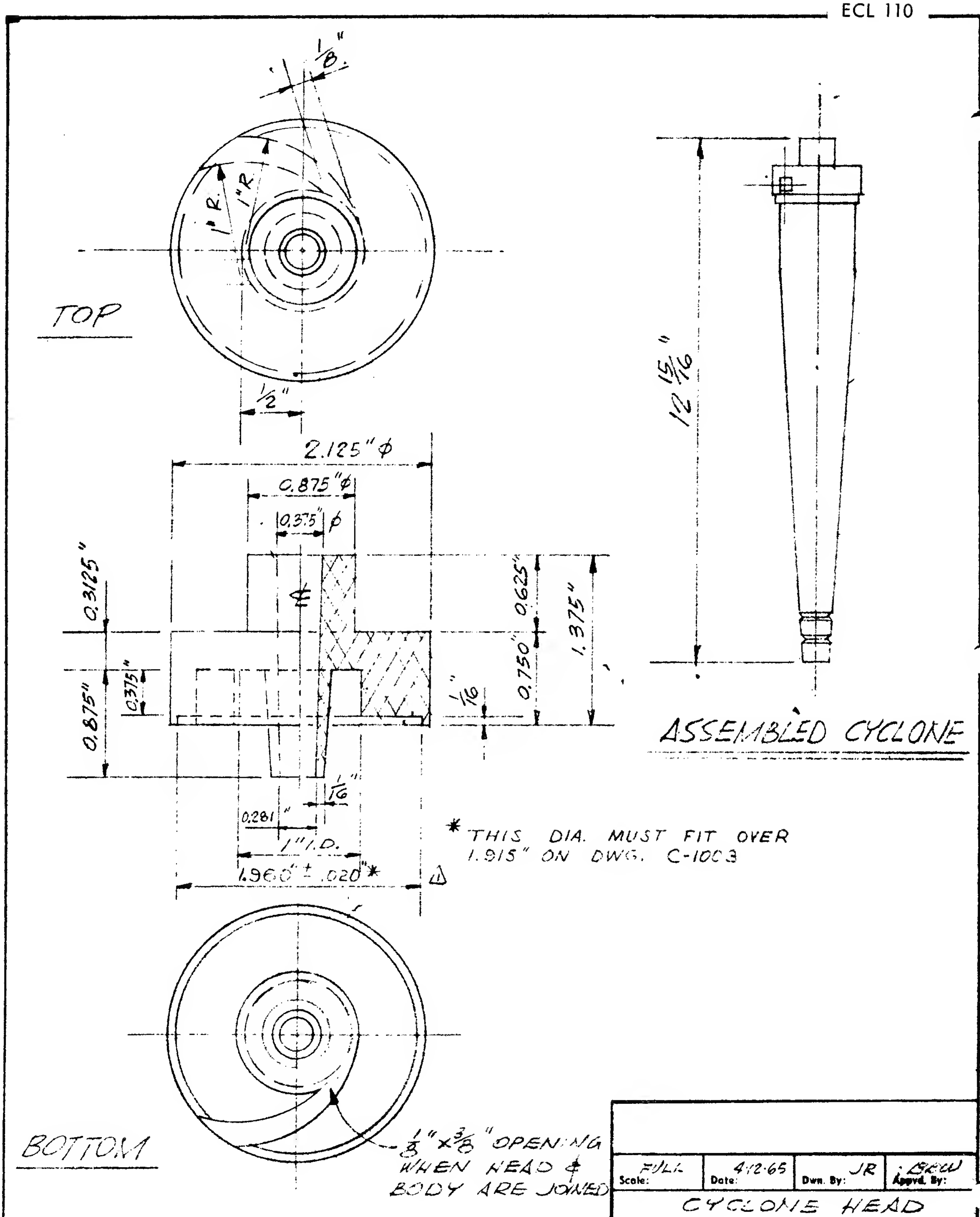
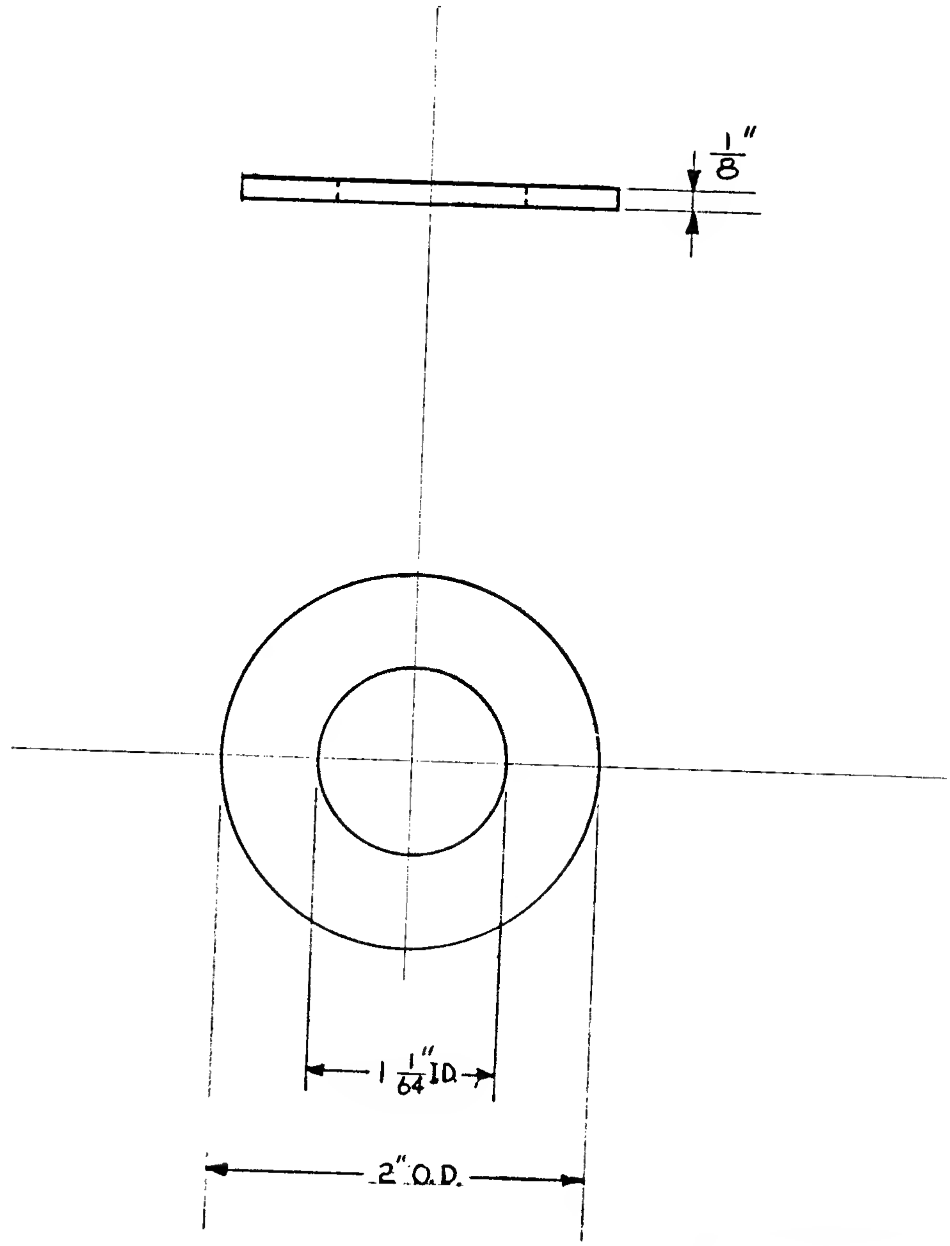


EXHIBIT 4 CYCLONE HEAD

ECL 110

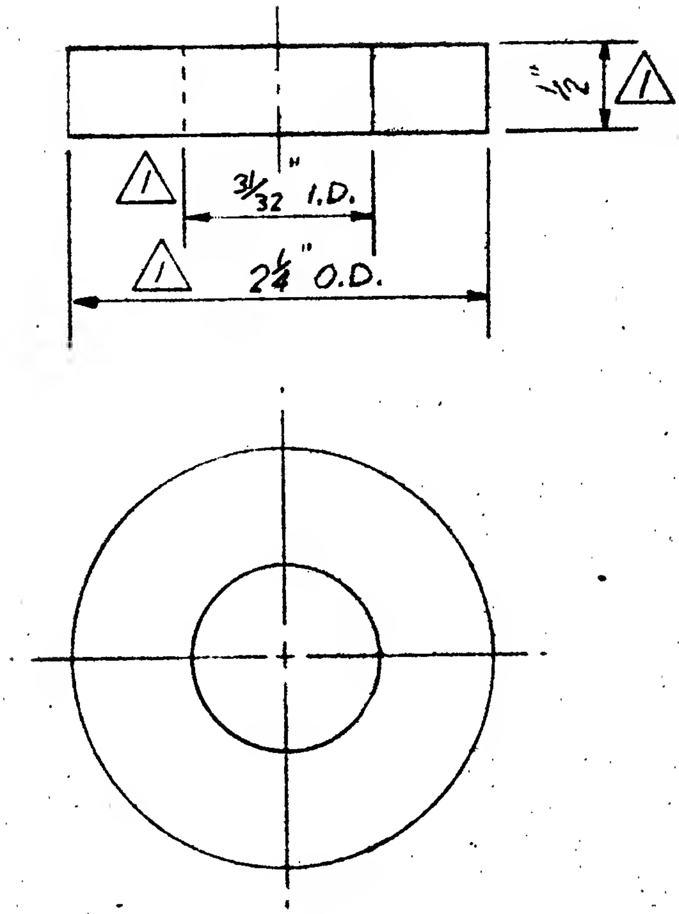


NOTE:

C1013ST MATERIAL: STEEL
C1013SS MATERIAL: STAINLESS STEEL

EXHIBIT 5 STEEL WASHER

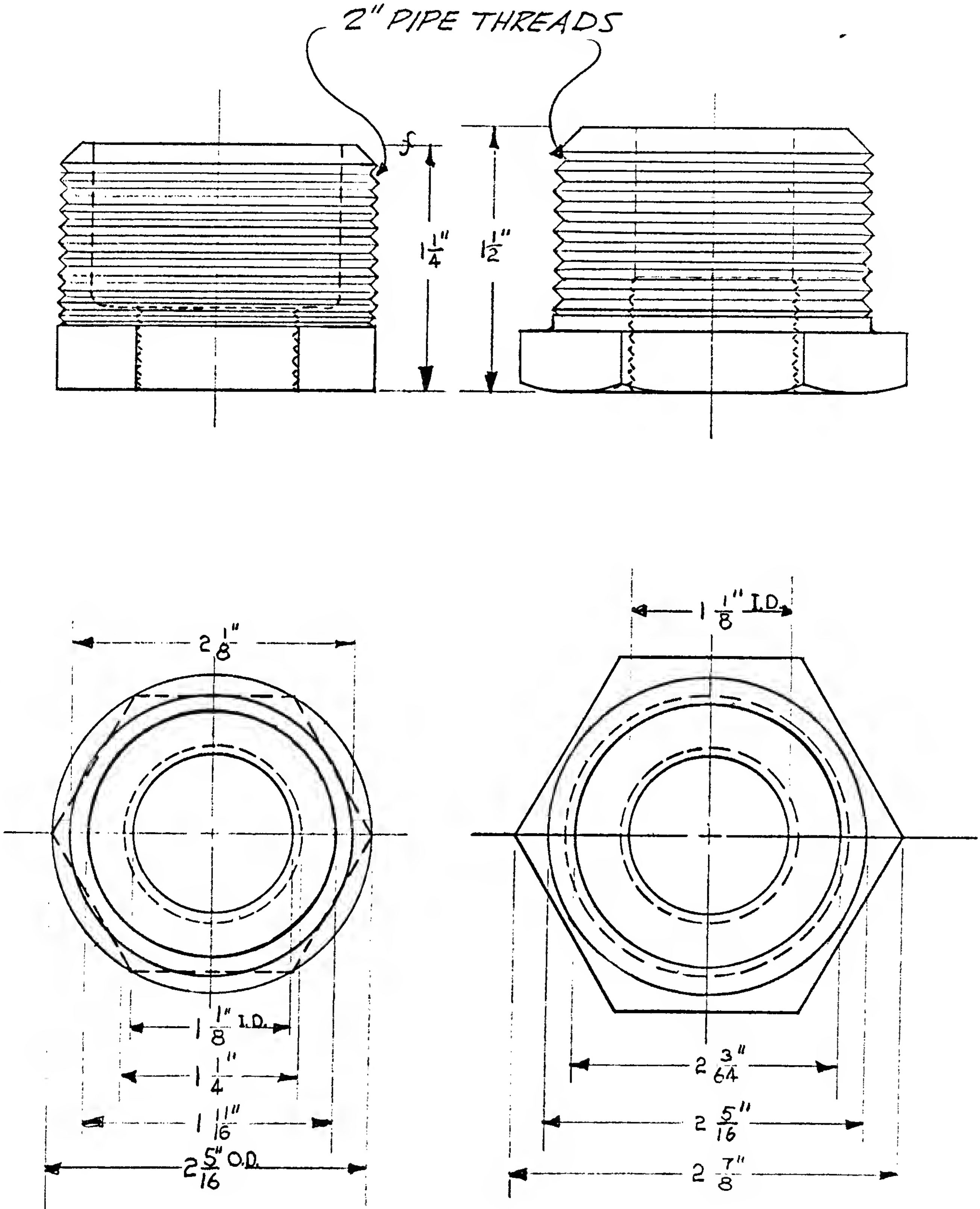
Scale: FULL	Date: 2-18-66	Dwn. By: JK	Apprd. By: BBW
WASHER PART No. C1013			
Revisions:		DWG. NO. C1013	



MATERIAL: RUBBER

EXHIBIT 6 RUBBER WASHER

Scale: FULL	Date: 2-18-66	Drn. By: JK	Appd. By: BEW
RUBBER WASHER PART No. C1014R			
Revisions: 10-26-66 REV. TO DATE - JK		DWG. NO. C1014	



NOTE:
C1015ST MATERIAL: STEEL
C1015SS MATERIAL: STAINLESS STEEL

EXHIBIT 7 BUSHING

Scale:	Date: 2-18-66	Dwn. By: JK	Appvd. By: BEW

BUSHING 2" x 1"
PART No. C1015ST

Revisions:	DWG. NO. C1015

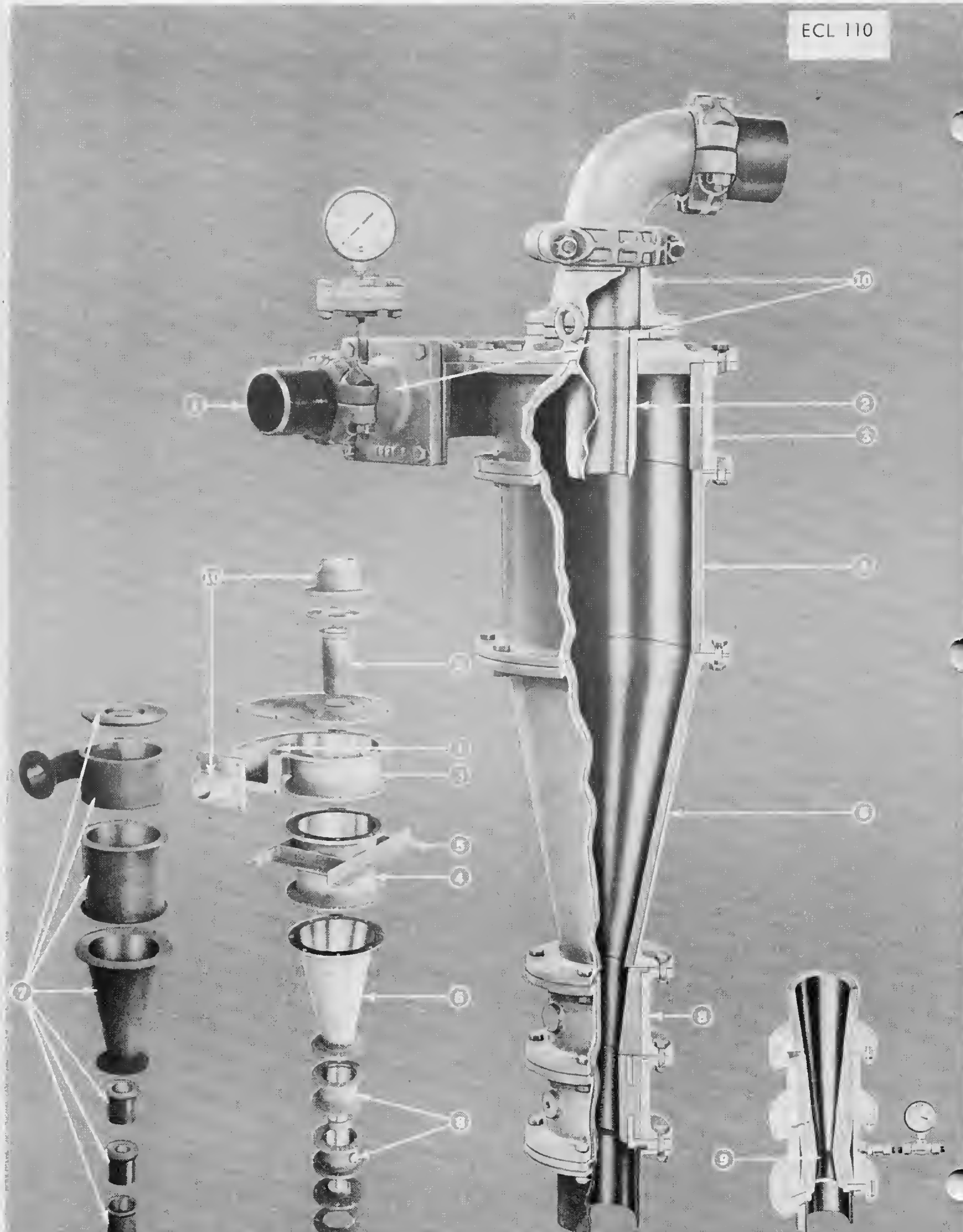
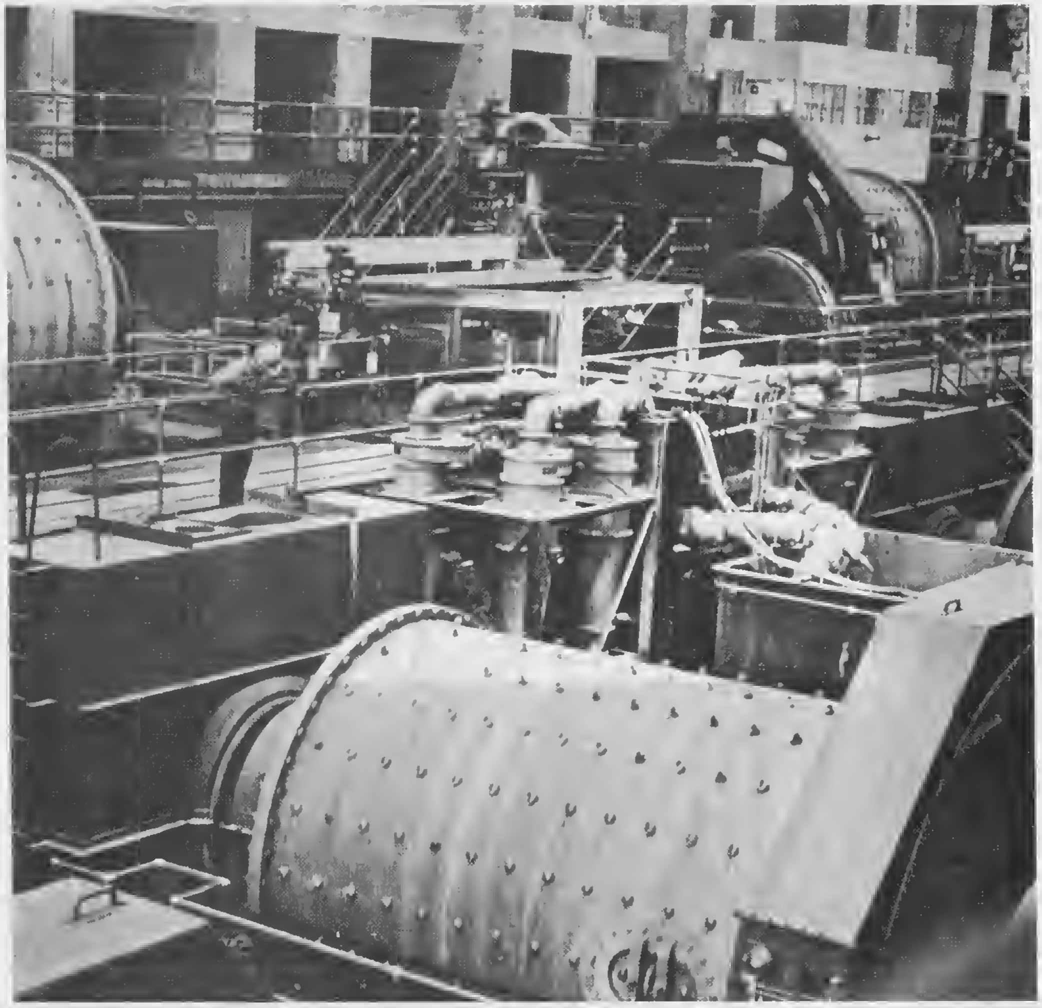


EXHIBIT 8 CUT-AWAY VIEW OF CYCLONE



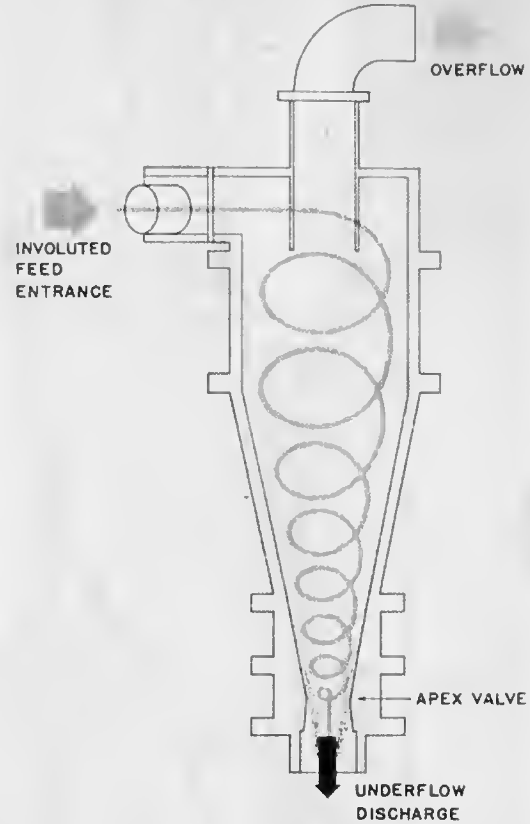


EXHIBIT 9 VIEW OF INSTALLATION AND SCHEMATIC OF CYCLONE ACTION

Table 8. Cyclone Pressure Drop Correlations

Source	Size of Cyclone (D_c)	Equation		Equation applied to a 9° cyclone with $D_i = D_c/7$, $D_o = D_c/5$, Q in l./min, Δp in psi, D_c in cm
		Form	Units	
Theoretical 1. Bradley	Any	$\frac{\Delta p/\rho}{V_i^2/2g_c} = \frac{\alpha^2}{n}\left[\left(\frac{D_c}{D_o}\right)^{2n} - 1\right]$ where α and n are factors dependent on cyclone design and fluid properties. α is also dependent on flowrate	Dimensionless	$\Delta p = 24{\cdot}3\,.\,Q^2/D_c^4$ using $\alpha = 0{\cdot}45$, $n = 0{\cdot}8$
2. de Gelder	Any	$Q = \xi\,.\,A_i\,.\left(\frac{2\Delta p}{\rho}\right)^{0.5}$ where $\xi = \frac{\xi_\infty}{1 - \frac{J}{6}\cdot\frac{A_c}{A_i}\left(\frac{2}{\mathrm{Re}\,.\sin\theta/2}\right)^{0.5}}$ ξ and J are factors dependent on cyclone design	Dimensionless	$\Delta p = 1{\cdot}45\left(\frac{1{\cdot}35}{\xi^2} - 1\right)\frac{Q^2}{D_c^4}$ where $\xi = \frac{0{\cdot}164}{1 - 515/\mathrm{Re}^{0.5}}$
3. Trawinski		$Q = K\,.\,D_i\,.\,D_o\,.\left(\frac{\Delta p\,.\,g_c}{\rho}\right)^{0.5}$ where K is a factor which contains diameter ratios, friction loss and cone angle variables for θ = 15 to 30°, $K = 0{\cdot}5$	Consistent units	$\mathrm{Re} = 5{\cdot}1 \times 10^6\,.\,\frac{Q}{D_c}$ $\Delta p = 19{\cdot}8\,.\,Q^2/D_c^4$
Empirical 4. Chaston	0·6 in to 27 in	$Q = 10\,.\,A_i\,.\,\Delta p^{0.5} \pm 20\%$	Imp. gal/min in², psi.	$\Delta p = 78\,.\,Q^2/D_c^4$
5. Dahlstrom	9 in	$Q/H^{0.5} = 6{\cdot}38(D_o\,.\,D_i)^{0.9}$ (See Note 1)	U.S. gal/min ft of fluid inches	$\Delta p = 13{\cdot}3\,.\,Q^2/D_c^4$
6. Elcox	Unknown	$Q = 24{\cdot}7\,.\,K\,.\,D_i^2(\Delta p/\rho)^{0.5}$ where K the discharge coeff. is 0·35	Imp. gal/min in., psi, g/cm³	$\Delta p = 64{\cdot}5\,.\,Q^2/D_c^4$
7. Haas	0·16 in to 0·4 in	$H = \frac{0{\cdot}07\,.\,Q^{2.27}}{D_c^{0.8}\,.\,D_i^{1.3}\,.\,D_o^{2.0}}$	U.S. gal/min ft of fluid inches	$\Delta p = 21{\cdot}2\,.\,Q^{2.27}/D_c^{4.1}$
8. Yoshioka and Hotta	3 in to 6 in	$\frac{\Delta p/\rho}{V_i^2/2g_c} = 54{\cdot}3\,\frac{(D_i/D_c)^{2.6}}{(D_o/D_c)^{1.9}}$	Dimensionless	$\Delta p = 39\,.\,Q^2/D_c^4$
9. Rietema	75 mm	$\frac{\Delta p}{\frac{1}{2}\rho V_i^2} = k_1\left(\frac{D_i}{D_o}\right)^{k_2}\left(\frac{D_c}{L}\right)^{0.7}(1 - R_f)^{0.8}$ at Re Inlet = 25000 (see Note 2)	Dimensionless	$\Delta p = 23\,.\,Q^2/D_c^4$

Table 8. Cyclone Pressure Drop Correlations—*Continued*

N.B. For Q in Imp. gal/min and D_c in inches, divide the final column Dahlstrom constant by 1·40, the Haas constant by 1·48, and the remaining constants by 2·03.

Note 1. Constant later given as varying from 5·5 to 6·5, being higher with smaller cone angles or longer cylinder lengths.[17] Original equation determined empirically for a range of variations in D_o/D_u of 0·6 to 2·0. Matschke and Dahlstrom modified the constant for small diameter cyclones to 6·94.

Note. 2. See Figs. 36, (a), (b), and (c).

EXHIBIT 10 TABLE OF EQUATIONS FOR PRESSURE DROP